Construction and first evaluation of a newly developed tactile Shear Force Display

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At present, tactile displays are constructed either as shape or vibrotactile displays. While shape displays render the shape of objects to the skin, vibrotactile devices display high frequent but small amplitude patterns of forces. Existing tactile displays of both types base on an array of small pins, which move normal to the contact surface. That is, the pins create a pattern of indentation into the skin. Usually, the devices are applied to the human finger pad.

However, in order to produce a realistic tactile impression of the environment it is probably as important to provide forces lateral to the human skin, so called shear forces. This is particularly reasonable when considering perceptions evoked by movements of the skin relative to the environment, e.g. when stroking with the finger across a surface.

We aim at technically realizing a third type of tactile display which can provide shear forces. The poster presents the prototype of a shear force display for the finger tip and a first psychophysical evaluation. In order to explore whether the stimuli produced by the display are appropriate for human perception we studied in a first step discrimination performance of humans for distinguishing between different directions of pin movement. This basic psychophysical knowledge that so far did not exist because the technology was not yet available will in return be used to improve the design of the display.

Technical realization of the shear force prototype display

The fundamental concept of the display is based on a quadratically arranged 2×2 pin array. To exert shear force to the area of the finger tip, each pin is movable lateral to the skin. Thereby it is possible to move each pin independently along both axes of their two-dimensional horizontal directions. Design parameters have been chosen based on psychophysical thresholds. A pin diameter of 1 mm, a center-to-center pin spacing of 3 mm (zero position of lateral movement) and a lateral movement of 2 mm along each axis and for each pin are realized [1].

To allow for this movement the four pin bodies are attached with universal-joint shafts that are screwed to the ground plate of the chassis. Two rods orthogonal attached to the upper region of each pin transmit two-dimensional movement of the pins. The rods are connected over reduction rocker arms to the servo motor levers. To decouple the axes of motion between the pin body and the reduction rocker arms ball joints on both ends of the rods are used. This ensures small backlash.

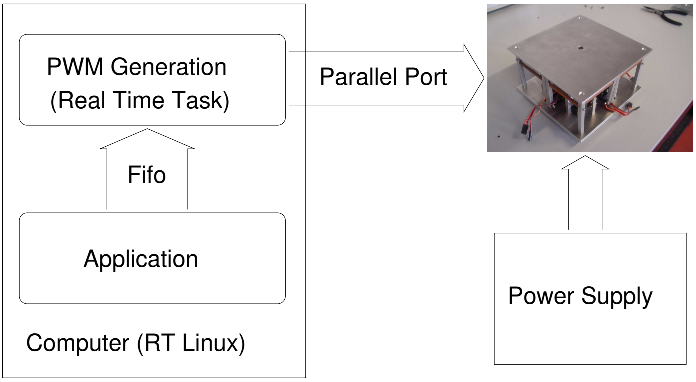

Fig. 1. Computer Interface

On the actuator side, we use of-the-shelf servo motors, selected on criteria like high performance, small deviations, and lightweight. The servo motors come with a position control circuit, accessed by a pulse width modulated signal, that contains the commanded position information. Fig. 1 shows the schematic design of the computer interface. A real-time task generates the required signals for the eight servo motors at the printer-port of the computer, whose data lines are connected to the corresponding servo motors. In the application process the position information for the servo motors are calculated and communicated to the real-time task. To provide sufficient power for the servo motors an external power supply is used.

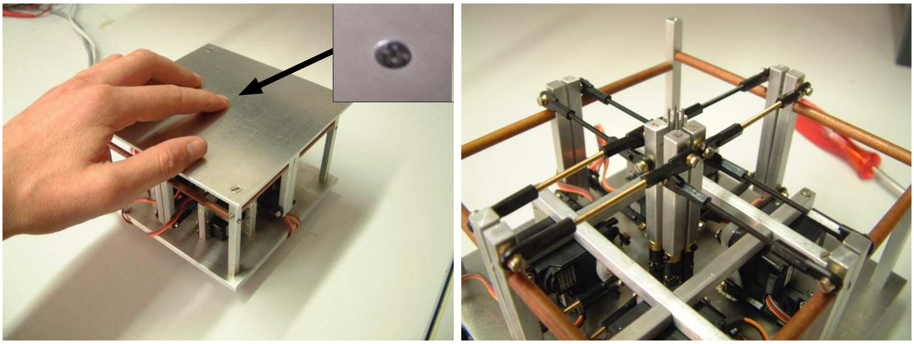

Fig. 2. Hardware setup of the shear force display

The left picture in Fig. 2 shows the display in use with a close-up view of the pin area that is in contact with the finger pad through a hole in the cover plate. A more detailed view in the right picture of Fig. 2 shows the mechanical details of the display like the pin bodies, the control rods, and the servo motors. Tab. 1 summarizes the technical data of the tactile shear force display.

Table 1. Technical data of the shear force display

Property	Value
Positioning resolution	10 μm
Max. pin force (per axis)	4.23 N
Max. pin velocity	22.8 mm/s
Pin work space	2×2 mm
Size	$150 \times 150 \times 90$ mm
Weight	1100 g

Psychophysical evaluation of the shear force effect

We investigated discrimination performance for movement direction on the skin displayed by a single pin of the shear force device (for this experiment the other 3 pins were removed). Participants were presented with unidirectional single strokes of 1 mm length (velocity 1 cm/s) displayed at the tip of their left index finger. For the strokes we defined eight standard directions with respect to the finger (separated by 45°). To each standard a set of 19 comparison strokes was chosen, the directions of which were distributed in 10° steps around the corresponding standard within an area of $\pm 90°$. In each trial the participants successively felt a standard and a comparison stroke and, then, had to decide which of the two strokes had been oriented more in clockwise direction. Each pair was presented 12 times. From the data we derived 84%-

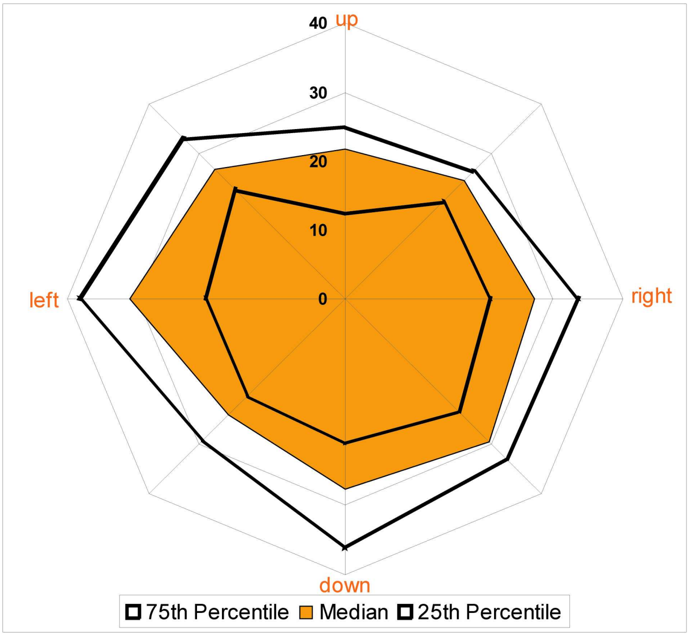

Fig. 3. Medians and quartiles of 84%-thresholds by standard direction

discrimination thresholds using the psignifit toolbox version 2.5.41 for Matlab (see `http://bootstrap-software.org/psignifit/`, [2]). We tested 14 paid right-handed participants (age range 21 to 40 years).

Fig. 3 depicts the medians and quartiles of the discrimination thresholds in the sample separated by standard direction. In general, participants were well able to discriminate between the directions of the movements displayed (threshold quartiles ranged from a maximal 75%-percentile of $38°$ down to a minimal 25%-percentile of $12°$). Further, the individual thresholds per standard direction entered a Friedman test. The test marginally failed to reach significance, $\chi^2(7) = 12.83, p = 0.076$. This result indicates that there was no strong effect of a particular standard direction on the discrimination threshold.

Conclusion

Taken together, the findings demonstrate that the shear force display produces tactile stimuli that are appropriate for human perception, in that shear forces seem to be usable to obtain a differentiated impression of at least one environmental aspect. It is also important to note that the technical directional resolution of the shear force device clearly exceeds the perceptual thresholds we found and that there was no pronounced perceptual anisotropy. Further development of the device may take advantage of these facts. Future evaluation of the present prototype will explore to what degree differential shear forces displayed by more than one pin can be discriminated (or are integrated) and the kinds of percepts the display is able to evoke.

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